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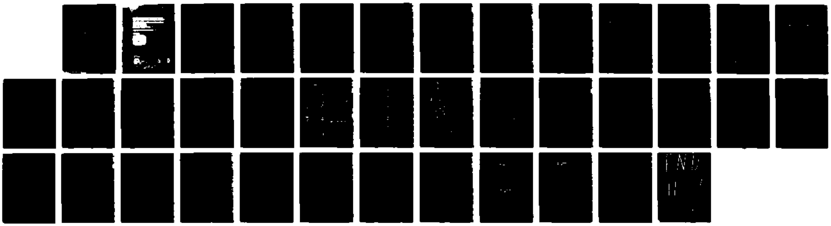

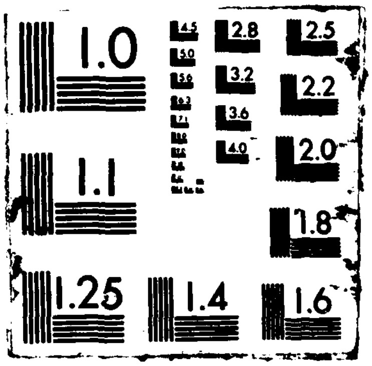
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19 June 1987

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This memo describes the modeling of the superheterodyne radar receiver and defines the parameters of interest. The modeling details are included. Both a flow chart and source code (FORTRAN) for the model are included. The report ends with documentation of the model testing and validation.

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Software Analysis and Management System

ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT # 1

EAAF

Technical Memorandum No. 16

19 June 1987

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ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT # 1

FOREWARD

Interim report # 1 describes progress to date of the ELINT Parameterization and Definition Study. The introduction describes the purpose of the study and explains why it was decided to model a superheterodyne receiver and defines the parameters of interest. A description of the model follows in section 2. A flow diagram and the source code of the model are included in sections 3 and 4 respectively. The report is concluded with documention of results and conclusions in section 5.

EXECUTIVE SUMMARY

This Technical Memorandum was prepared originally as part of the Generic ELINT/COMINT Sensor Report (FY-85/FY-86) which was elmininated under the FY-87 statement of work (SOW #2), undated (delivered to JPL 19 November 1986).

The purpose of the Generic ELINT/COMINT Sensor Report, of which this paper was intended (in its final form) to become part of, was to establish a basic superhetrodyne receiver based sensor model and perform simulations with it to determine the shaping or coloring of the statistical distributions of the radar free-space signal parametrics by a typical sensor prior to reaching the self-correlation processes. It was also intended for incorporation into the algorithm test bed so algorithms could be tested with realistic distorted data rather than unrealistic stastically pure data.

This work was originated in support of unanswered questions from previous self-correlation studies. The modeling and simulation approach was used because "live date" could not be obtained.

This paper is being published because it was completed in FY-86 with FY-86 funds and still serves a useful function.

There were no unexpected results at this stage of the models development - the model has been verified as valid. The second stage of this study is to analyze the shaping or coloring of the radar free-space signal parametrics and may not be completed due to the restrictions of the current JPL Task Plan.

ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT # 1

0.0 EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 RECEIVER MODEL DEVELOPMENT

- 2.1 SQUARE LAW DETECTOR AND LOW PASS DETECTOR
- 2.2 VIDEO AMPLIFIER
- 2.3 CONSTANT FALSE ALARM RATE (CFAR)
- 2.4 PULSE DETECTOR
- 2.5 LIMITER
- 2.6 DISCRIMINATOR

3.0 RECEIVER PROGRAM FUNCTIONAL FLOWCHART

4.0 SOURCE CODE

5.0 RESULTS AND CONCLUSIONS

ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT # 1

1.0 INTRODUCTION

The purpose of this report is to define the statistics of the observed parameters of interest of a generic ELINT sensor. The approach chosen was to "build" a computer model of a typical ELINT receiver and excite it with input signals of known distributions and then measure the resulting output distributions.

1.1 THE "SUPERHET"

The superheterodyne receiver has many advantages to offer for the gathering of electronic intelligence. It is the most widely used receiver design for nearly all uses including ELINT applications. A basic functional block diagram is shown in Figure 1.1. The idea is to use a local oscillator to convert the incoming signal to a fixed intermediate frequency (IF) by the mixing process called heterodyning. Thus the IF amplifier need operate at only one (lower) frequency and it's operating characteristics may be carefully and more economically controlled. Bandwidths for typical narrowband ELINT receivers are approximately 20 MHz for B_{RF} or B_{IF} and 10 MHz for B_V. This ensures good pulse fidelity for nominal radar pulsewidths of 1 microsecond or greater. The simple receiver of Figure 1.1 has been used with great sucess since World War II. Recent innovations have greatly increased the basic capabilty of the superhet. By rapidly sweeping the local oscillator in frequency an amplitude versus frequency display may be generated thus creating an RF spectrum analyzer. Very rapid sweeping creates a rapid sweep superhet that is useful for detecting high duty cycle, low power signals in the presence of low duty cycle interfering signals*. In addition heterodyning techniques are used in the implementation of compressive and microscan receivers and many instantaneous frequency measurement (IFM) receiver designs utilize superhet frontends.

So we see that the study of superhet receivers is a good place to begin.

* R. G. WILEY, *ELECTRONIC INTELLIGENCE: THE INTERCEPTION OF RADAR SIGNALS*

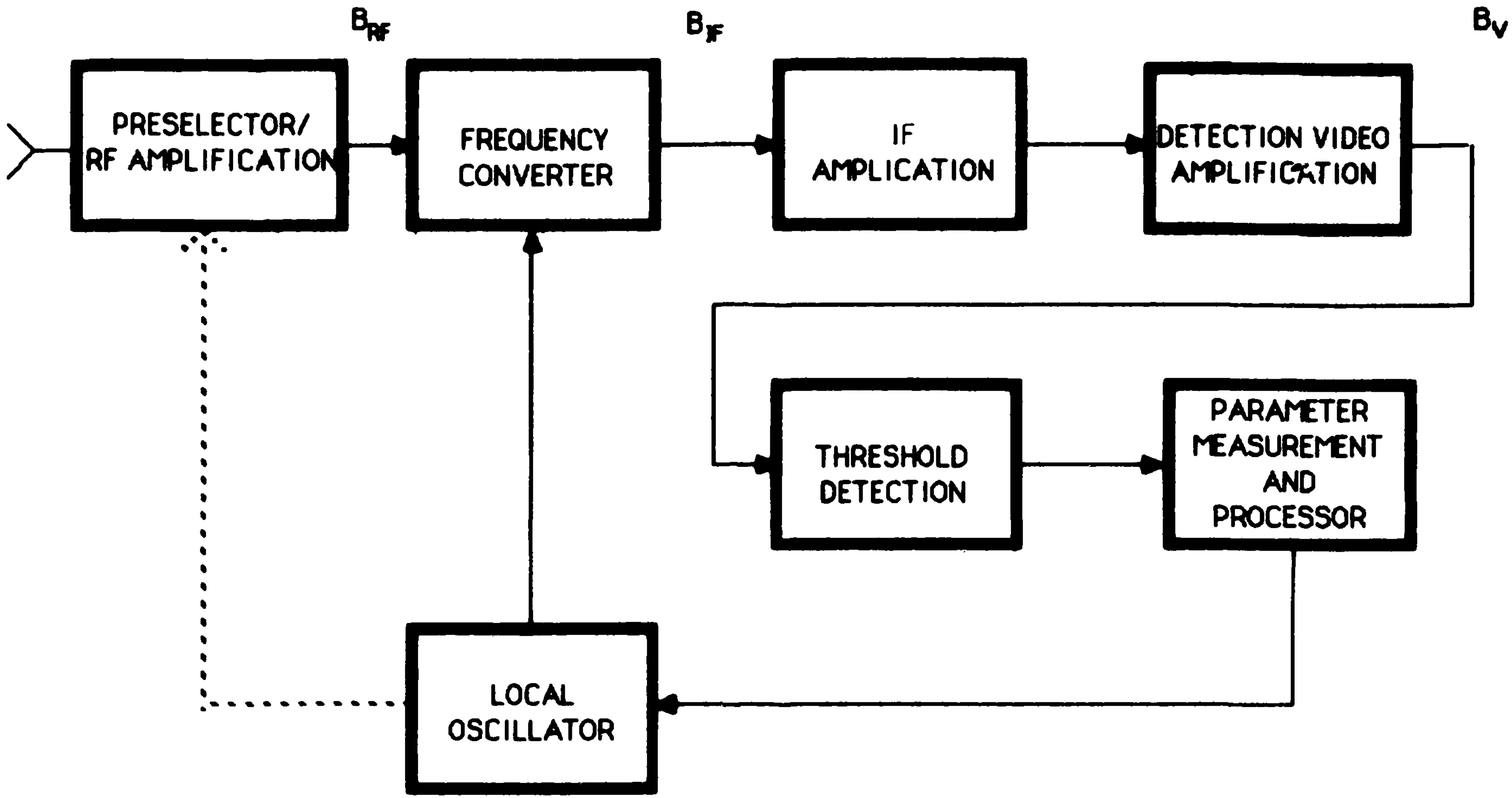

FIGURE 1.1 : FUNCTIONAL BLOCK DIAGRAM OF SUPERHETERODYNE RECEIVER

2.0 SENSOR MODEL DEVELOPMENT

Figure 2.1 is a functional block diagram of the simple receiver to be modeled. We first assume that the received signal is a narrowband process that is statistically unaltered by the downconversion to the IF frequency, ω_{IF}. Thus, the signal at the input of the detector and limiter is

(1) $r(t) = s(t)\cos[(\omega_c - \omega_0)t + \varphi(t)] + n(t)$ where

$s(t)$ = transmitted pulse envelope as modified by the transmission channel characteristics

ω_c = carrier frequency

ω_0 = LO frequency assumed to be noiseless

$\omega_{IF} = \omega_c - \omega_0$ = IF frequency

$\varphi(t)$ = signal phase at output of IF amplifier

$n(t)$ = additive receiver noise plus input noise.

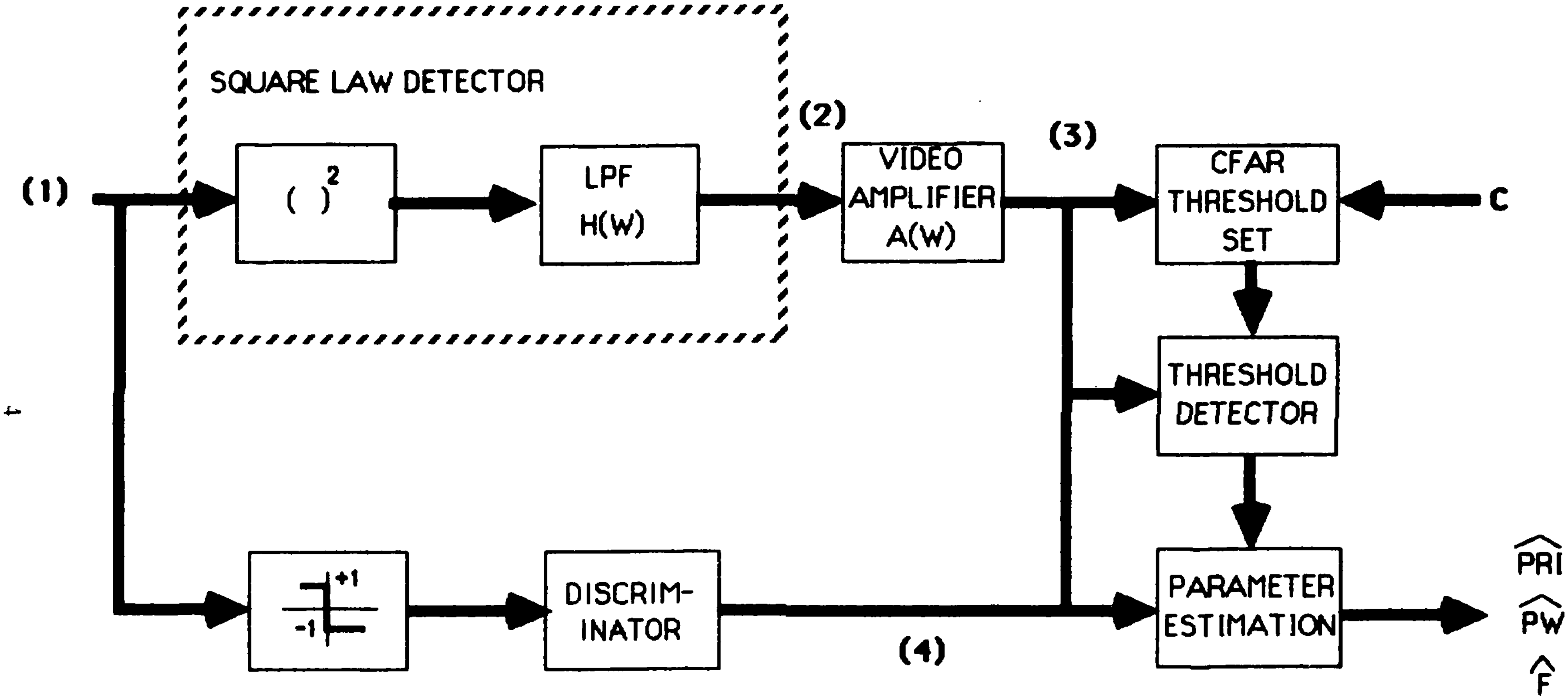

FIGURE 2.1 : SIMPLIFIED RECEIVER MODEL

2.1 SQUARE LAW DETECTOR AND LOW PASS FILTER

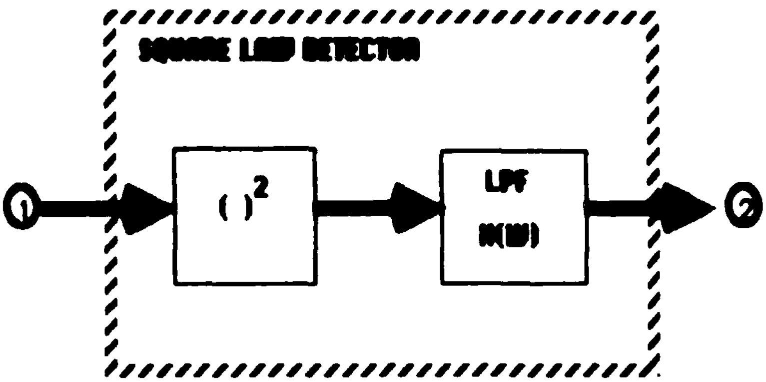

FIGURE 2.2 . Functional Block Diagram of a Square Law Detector

Figure 2.2 depicts functionally a square law detector. Squaring the input , (1) above, we obtain

$$r^2(t) = s^2(t)\cos^2[2\pi f_{IF}t + \varphi(t)] + 2s(t)\,\{\cos[2\pi f_{IF}t + \varphi(t)]\}\,n(t) + n^2(t) \qquad (1.1)$$

where $f_{IF} = 2\pi(\omega_C - \omega_0)$ is the receiver IF frequency.

Now, using

$$\cos^2 x = {}^1/_2\,(1 + \cos 2x)$$

(1.1) becomes

$$r^2(t) = {}^1/_2\, s^2(t) + {}^1/_2\, s^2(t)\cos 2[\,2\pi f_{IF}t + \varphi(t)] + 2s(t)\,\{\cos[(2\pi f_{IF})t + \varphi(t)]\}\,n(t) + n^2(t) \qquad (1.2)$$

Hence, by multiplying the received signal by itself we have obtained $^1/_2$ the square of the modulation waveform s(t) plus higher frequency terms consisting of cross products of the noise and the signal at the fundamental and second harmonic frequencies and the noise term $n^2(t)$. Now, by low pass filtering the output of the square law device as depicted in the above figure with a filter sufficiently wide to pass s(t) while rejecting those frequencies above the lowest component of s(t) that is of interest. One obtains at the output of the detector low pass filter the signal

(2) $$r_v^2(t) = {}^1/_2\, s^2(t) + \tilde{n}^2(t)$$

where $\tilde{n}^2(t)$ represents the low frequency components of the noise process $n^2(t)$.

For the purpose of this simulation the output filter of the detector will determine the bandpass response of the video channel. Good pulse fidelity requires that the filter have a bandpass adequate to pass the 12th harmonic with less than 75% attenuation*. Thus the filter is required to have a 3db bandwidth B_{3db} greater than or equal to 12 Mhz, assuming that the received pulse width is greater than or equal to 1 μsec.

* R. G. WILEY, *ELECTRONIC INTELLIGENCE: THE ANALYSIS OF RADAR SIGNALS*

2.2 VIDEO AMPLIFIER

The video amplifier provides additional gain and bandpass shaping if required. for this simulation the gain will be set to K with an infinite frequency response. Thus, the bandpass response of this portion of the receiver is determined by the low pass filter of the detector and

$$A(\omega) = K$$

where K is selectable as an user input into the simulation and defaults to the value required to provide unity gain to the detector and, thereby, simplifying later calculations.

2.3 CONSTANT FALSE ALARM RATE (CFAR)

The CFAR is a circuit that maintains a reference voltage level proportional to the received in band noise. Thus, it may be used to vary the threshold of the pulse detection circuitry in such a way to prevent false alarms due to varying noise levels at the input of the receiver. The CFAR constant ,C, is adjusted to provide a desired false alarm rate(FAR). The results reported herein were based upon a calculated FAR = 10^{-4}.

2.4 PULSE DETECTOR

The pulse detector circuitry compares the output of the video amplifier to the threshold determined by the CFAR circuit and strobes a pulse present signal to the parameter estimation circuit when the video signal is greater than the threshold. A threshold is chosen to provide a desired probability of detection (P_D).

2.5 LIMITER

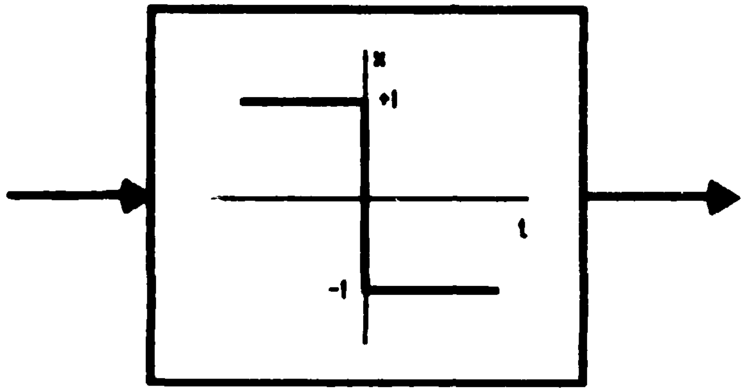

FIGURE 2.3. FUNCTIONAL BLOCK DIAGRAM OF A HARD LIMITER

A functional block diagram of a hard limiter is depicted in Figure 2.3. The limiter conditions the input signal to the frequency discriminator by amplifying and clipping an I.F. output signal to provide essentially a square wave input to the discriminator at the frequency of the IF signal. If the input to a hard limiter is $x(t)$ then the output, $y(t)$, is

$$y(t) = \begin{cases} 1 & x(t) \geq 0 \\ -1 & x(t) < 0 \end{cases}$$

2.6 DISCRIMINATOR

The discriminator provides the frequency estimation function for the receiver. It consists of a zero crossing counter that counts and stores the number of zero crossings during the pulse. When the threshold circuit detects a pulse it provides a strobe that initializes and starts the zero crossing counter. At the end of the pulse the contents of the counter are read and the average frequency of the I.F. pulse is calculated based upon the estimated pulsewidth.

3.0 SENSOR MODEL FUNCTIONAL FLOW CHART

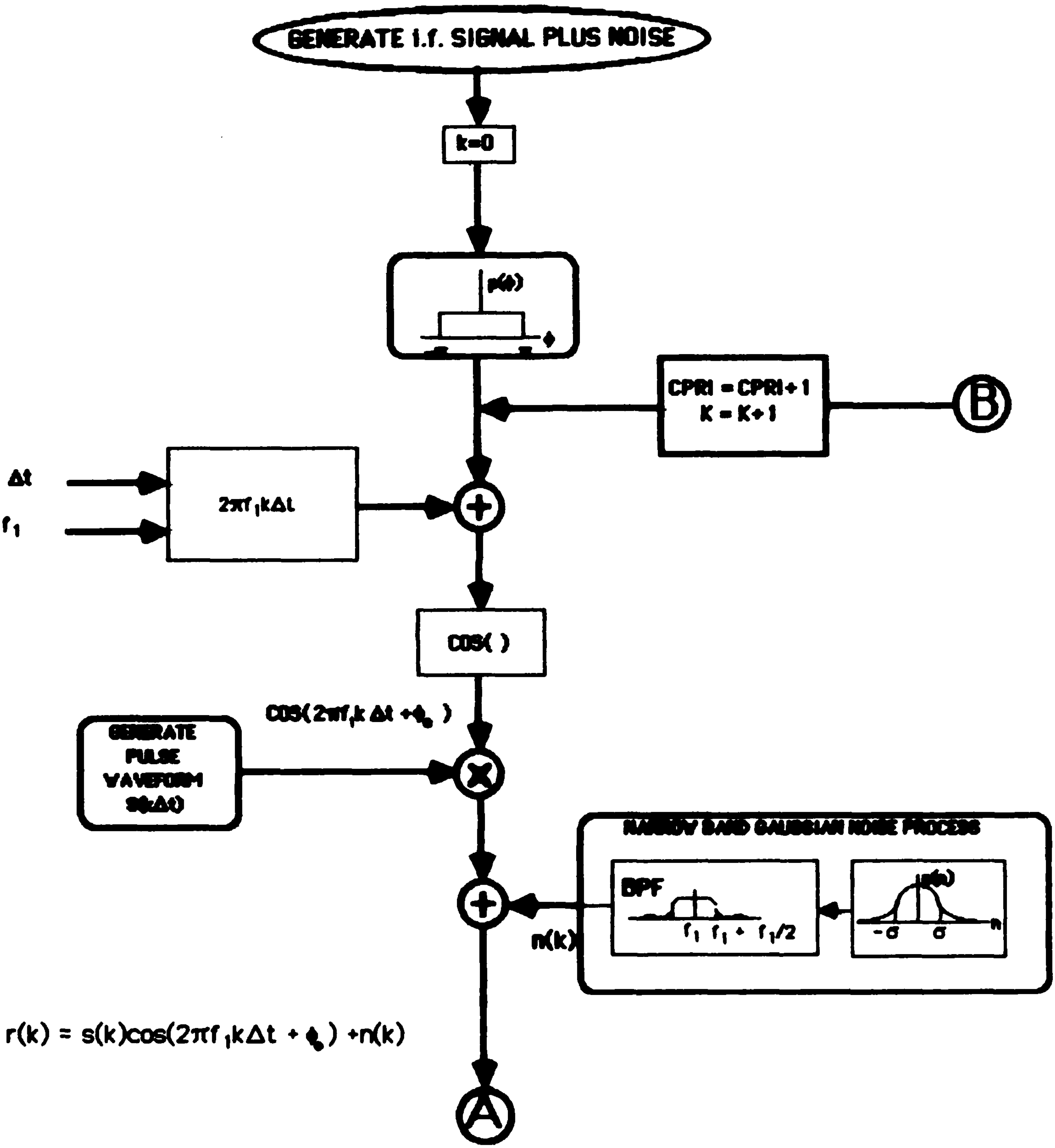

FIGURE 3a: RECEIVER SIMULATION FLOW CHART

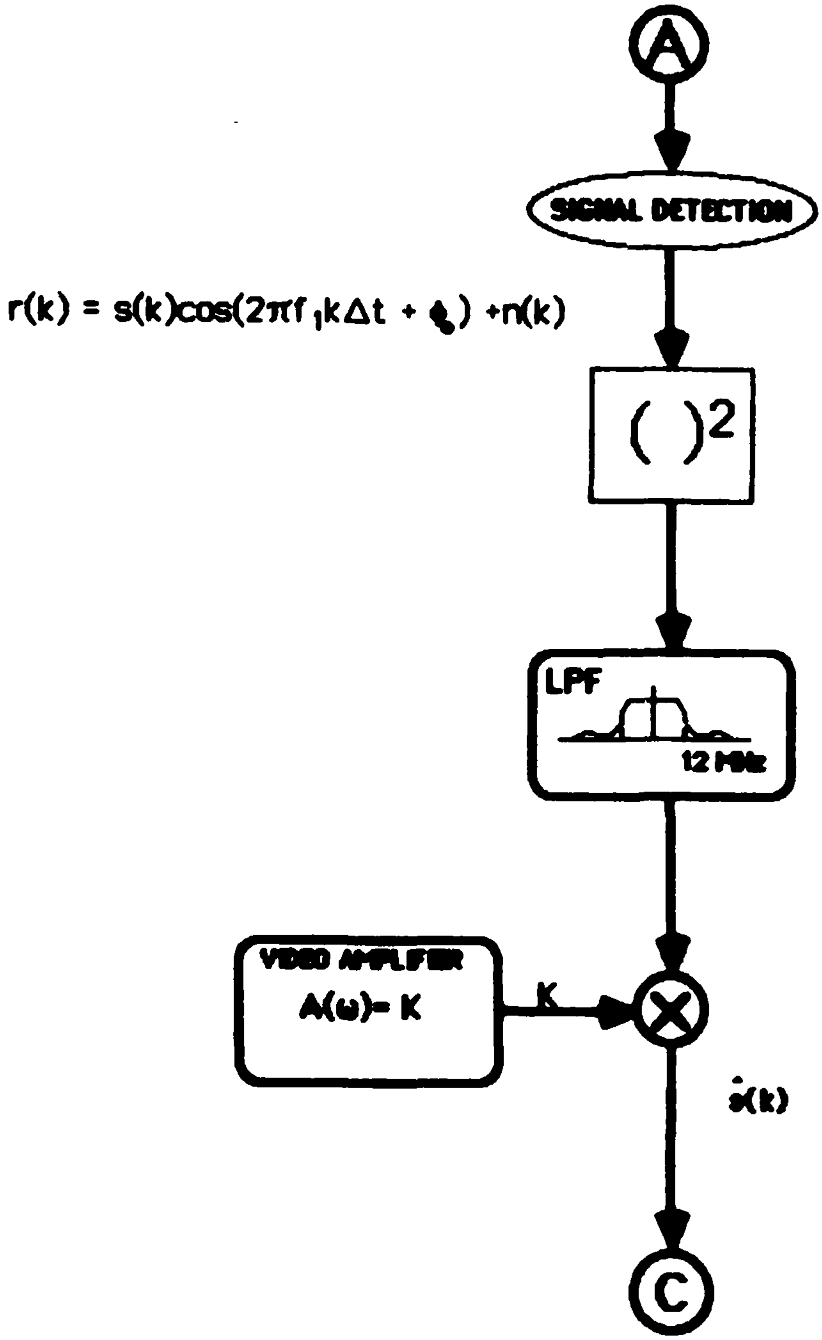

FIGURE 3b: RECEIVER SIMULATION FLOW CHART (CONTINUED)

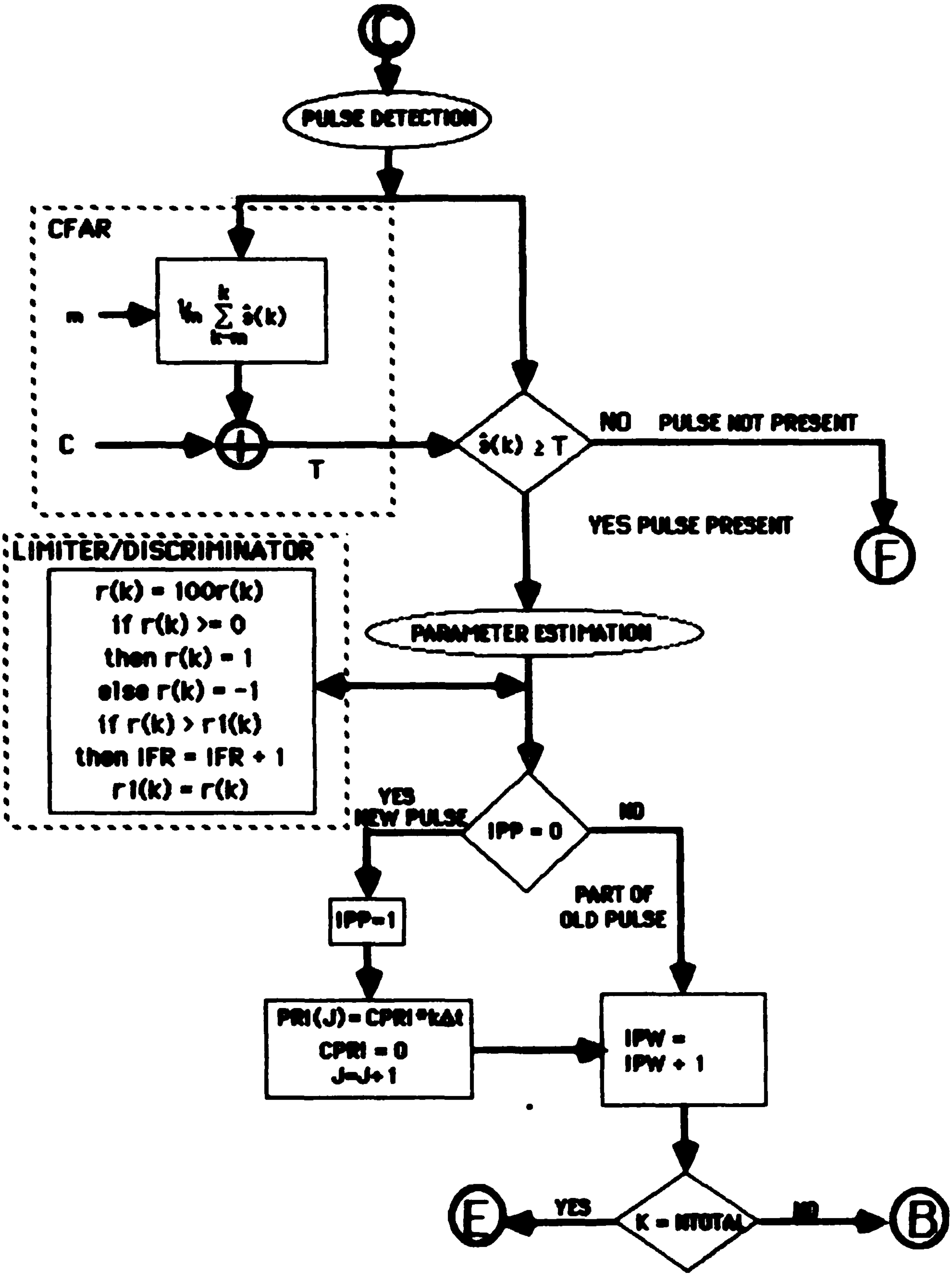

FIGURE 3c: RECEIVER SIMULATION FLOW CHART (CONTINUED)

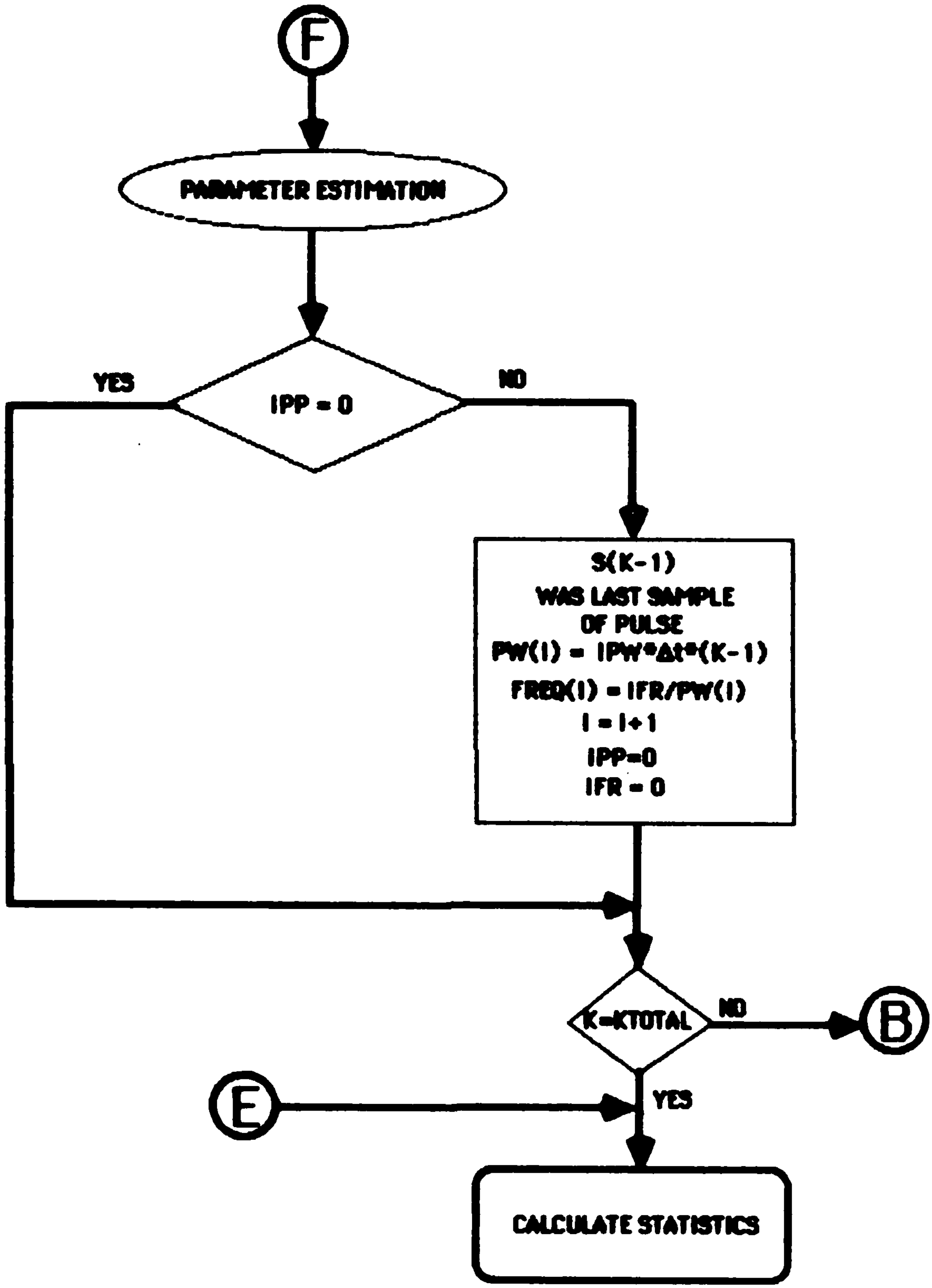

FIGURE 3d: RECEIVER SIMULATION FLOW CHART (CONTINUED)

4.0 SOURCE CODE LISTING

```
************************************6:34:07 PM  3/29/86********************************
*THIS PROGRAM SIMULATES A SIMPLE SUPERHETERODYNE RECEIVER THAT UTILIZES A
* SQUARE LAW DETECTION PROCESS. THE IF OUTPUT SIGNAL IS FIRST GENERATED AS-
* SUMING THAT THE RECEIVED SIGNAL IS A PULSED RADAR SIGNAL OF CONSTANT
* FREQUENCY, RANDOM PHASE, AND CORRUPTED BY AN ADDITIVE GUASSIAN NOISE CHAN-
* NEL.
*
*
* GENERATE THE RECEIVER IF SIGNAL
*
*
****************************************************************************
* K      -- SAMPLE COUNTER
* KTOTAL -- TOTAL NUMBER OF SAMPLES TO BE GENERATED
* SNR    -- SPECIFIED SIGNAL-TO-NOISE RATIO OF RECEIVED SIGNAL
* R(K)   -- RECEIVED SIGNAL AT OUTPUT OF I.F. AMPLIFIER
* F1     -- I.F. FREQUENCY
* DELT   -- THE SAMPLE INTERVAL DELTA T
* PHI    -- RANDOM PHASE OF THE RECEIVED SIGNAL R(K)
* S(K)   -- PULSE ENVELOPE OF RECEIVED SIGNAL
* PWID   -- PULSE WIDTH
* M      -- NUMBER OF CFAR INTEGRATION SAMPLES
* C      -- CFAR CONSTANT
* G      -- VIDEO AMPLIFIER GAIN
* IPP    -- PULSE PRESENT INDICATOR
* IFR    -- DISCRIMINATOR ZERO CROSSING COUNTER
* CPRI   __ PRI SAMPLE COUNT
* IPW    -- PULSE WIDTH SAMPLE COUNT
* PRI(N) -- MEASURED PULSE INTERVAL OF NTH PULSE
* PW(N)  -- MEASURED PULSE WIDTH OF NTH PULSE
* FREQ(N) -- MEASURED FREQUENCY OF NTH PULSE
****************************************************************************
*
*
*DECLARATIONS
*
*
   INTEGER K, IPP, J, I, IFR, CPRI, IPW, L,O,O1 ,Q
      Integer*4 TICKCOUNT,TICK1,TICK2,toolbx
      REAL Y(4200),X(4200),R(4200), PRI(1000), PW(1000), FREQ(1000)
      REAL H(32),HL(24),RDET(4200)
      PARAMETER (TICKCOUNT=Z'97580000')          ! toolbox definitions
      DATA (H(I), I=1,16)/-.57534121E-02, .99027198E-02,1.75733545E-02,
```

```
1-.65141192E-02, .13960525E-01, .22951469E-02,
1-.19994067E-01,.71369560E-02,
1 -.39657363E-01, .11260114E-01, .66233643E-01,
1-.10497223E-01, .85136133E-01, -.12024993E-00,
1-.29678577E00,.30410917E00/
  DATA (HL(I), I=1,12)/0.33740917E-02,0.14938299E-01,
10.10569630E-01,
10.25415067E-02,-0.15929992E-01, -0.34085343E-01,
1-0.38112177E-01,-0.14629169E-01,
1 0.40089541E-01,0.11540713E00,0.13850752E00,
10.23354606E00/
*     PRINT *,' PULSE  PULSEWIDTH    PRI        FREQUENCY
*   1   SNR'
*   PRINT *,'                                   PREDETEC
*   1TION   POSTDETECTION'
*     OPEN(UNIT=18,FILE = 'RCVDATA')
      DO 111 I=17,32
      L=33-I
      H(I) = H(L)
111   CONTINUE
      DO 101 I=13,24
      L=25-I
      HL(I) = HL(L)
101   CONTINUE
98    WRITE(9,*) 'ENTER NUMBER OF PULSES, MINIMUM SNR, MAXIMUM  SNR'
************************INITIALIZE COUNTERS AND FLAGS******************
      READ(9,*) O,SNRMIN,SNR
      TICK1 = toolbx(TICKCOUNT)
      DELT = 2.5E-08
      F1 = 10.E06
      KTOTAL = 4000
      PWID =20.E-06
97    O1=0
      Q=0.
      SNSUM = 0.
      SNSUM1 = 0.
      PM=0.
      I1 = 1
99    IPP = 0
      IPW = 0
      J1 = 1
      IFR = 0
      PWRSIG = 0.
```

```
      PWRNOS = 0.
      PRESIG = 0.
      PRENOS = 0.
      KF=5555
*     WRITE(9,*) 'ENTER SAMPLE INTERVAL,I.F. FREQUENCY,NUMBER OF
*    1SAMPLES'
*     READ(9,*) DELT,F1,KTOTAL
      PI = 3.141593
*GENERATE RANDOM PHASE PHI
      SIGMA = 1./SQRT(SNR)
      PHI = RAND(0)             ! SEED THE RANDOM NUMBER GENERATOR
      PHI = (RAND(1) - .5)*2.0*PI
      IDELAY = 2000
      L = INT(PWID/DELT)
      DO 11 K=1,KTOTAL + 130
      TN = RAND(1)-.5
      XN = SQRT(LOG(1./(TN*TN)))
      XN = XN - (2.30753 + .27061*XN)/(1. + .99229*XN + .04481*XN*XN)
      XN = XN*SIGMA
      IF(TN.LT.0)  XN=-XN
*GENERATE PULSED IF SIGNAL
      IF (K .LE. IDELAY .OR. K .GE. L + IDELAY)     THEN
      R(K) = XN
      ELSE
        R(K) = 1.4142*COS(2*PI*F1*K*DELT + PHI) + XN
      END IF
 11   CONTINUE
* BANDLIMITED ZERO MEAN WHITE GAUSSIAN NOISE
* BANDPASS NOISE TO +/- F1/2
* FINITE IMPULSE RESPONSE (FIR) LINEAR PHASE BANDPASS DIGITAL FILTER
* -10DB POINTS ARE .14 AND .39 OF THE NYQUIST FREQUENCY
      DO 102 K=32,KTOTAL+130
      Y(K) = 0.
      DO 102 J = 1,32
 102  Y(K) = Y(K) + H(J)*R(K-J+1)    !BANDPASS LIMITED PULSE I.F. PLUS NOISE
      DO 21 K=1,KTOTAL+ 99
      Y(K) = Y(K+31)*Y(K+31)       !PERFORM SQUARE LAW DETECTION
      IF(K.LE.IDELAY-32 .OR. K.GE.IDELAY+L) THEN
        PRENOS = PRENOS + Y(K)*Y(K)/(KTOTAL + 67 - L)
      ELSE
        PRESIG = PRESIG + Y(K)*Y(K)/L
      END IF
 21   CONTINUE
```

```
      PRESNR = PRESIG/PRENOS
      PRESNR = PRESNR
      PSNRDB = 10*LOG10(PRESNR)
*********************LOW PASS FILTER DETECTOR OUTPUT***************
*****************-10 DB POINT IS .05 OF THE NYQUIST FREQUENCY************
      RDET(1) = 0.
      DO 202 K=1,100
      RDET(1) = RDET(1) + .01*Y(K)
202   CONTINUE
      DO 203 K=2,KTOTAL
      RDET(K) = RDET(K-1) + .01*(Y(K+99)-Y(K-1))
      IF(K.LE.IDELAY-130 .OR. K.GE.IDELAY+L) THEN
        PWRNOS = PWRNOS + RDET(K)*RDET(K)/(KTOTAL - L-130)
      ELSE IF (K.GE.IDELAY-130 .AND. K.LE.IDELAY+L) THEN
        PWRSIG = PWRSIG + RDET(K)*RDET(K)/(L-130)
      END IF
203   CONTINUE
      SIGNOS = PWRSIG/PWRNOS
      SIGNOS = SIGNOS - 1.0
      SIGNOSDB = 10.*LOG10(SIGNOS)
      SNSUM = SNSUM + SIGNOS/O
      SNSUM1 = SNSUM1 + PRESNR/O
********************PARAMETER ESTIMATION*********************
      T = SQRT(18.4*PWRNOS)
      DO 400 K=1,KTOTAL
      IF( RDET(K) .LT. T .AND. IPP=0 .AND. K=KTOTAL)  GO TO 206
      IF( RDET(K) .GE. T .AND. IPP=0 )  THEN
       KF=K
       T=T/2.                  !FIRST SAMPLE OF NEW PULSE
       IPP=1
       PRI(I1) = (2000. + K)*DELT*1000000.
       IPW = IPW + 1
      ELSE IF( RDET(K) .GE. T .AND. IPP=1 )   THEN
       IPW = IPW + 1
      ELSE IF( RDET(K) .LT. T .AND. IPP=1 )   THEN
       PW(I1) = IPW*DELT*1000000.
       GO TO 401
      END IF
400   CONTINUE
401   IF(KF.NE.5555) THEN
        DO 204  K=KF,KF+IPW
          IF(R(K).LT.0) THEN
             R(K) = -1.
```

```
            ELSE
              R(K) = 1.
        END IF
204     CONTINUE
        END IF
        DO 205  K=KF,K+IPW
205     IF(R(K).NE.R(K+1))    IFR = IFR + 1
        FREQ(I1) = IFR/PW(I1)/2.
*       PRINT 5002 ,I1,PW(I1),PRI(I1),FREQ(I1),PSNRDB, SIGNOSDB
*5002  FORMAT(1X,I4,3X,F10.4,3X,F10.4,8X,F10.4,4X,F10.4,2X,F10.4)
        GO TO 207
206     PM = PM + 1./O
*       PRINT 5003, I1,T,SIGNOSDB
*5003FORMAT(1X,I4,6X,16HMISSED DETECTION,5X,12HTHRESHOLD = ,F10.4,
*     15X,6HSNR = ,F10.4)
207   I1 = I1 + 1
        O1=O1-1
        IF (O1.GT.0) GO TO 99
        SNSUM = 10*LOG10(SNSUM)
        SNSUM1 = 10*LOG10(SNSUM1)
        WRITE(6,*) 'AVERAGE PREDETECTION SNR =   ',SNSUM1,'
     1AVERAGE POSTDETECTION SNR = ',SNSUM
        PD =(1. - PM)*100.
        WRITE(6,*) 'PROBABILTY OF DETECTION = ',PD, '   PER CENT'
        TICK2 = toolbx(TICKCOUNT)
        TIME = FLOAT(TICK2 - TICK1)/60.
        WRITE(6,*) 'ELAPSED TIME = ',TIME,'   SECONDS'
        SNR = SNR -.10
        IF(SNR-SNRMIN > 0.) GO TO 97
*       DO 91 K=1,KTOTAL
*       X(K) = RDET(K)
*       Y(K) = 0.0
*91     CONTINUE
*       CALL FFT4(X,Y,4096,6)
*       NTOTAL = KTOTAL/2
*       DO 40 K=1,NTOTAL
*     RDET(K) = X(K)*X(K) + Y(K)*Y(K)
*       RDET(K) = 10.*LOG10(RDET(K))
*40     CONTINUE
***************************AVERAGE ARRAY ******************************************
*       LTOTAL = NTOTAL/4
*       DO 50 K=1,LTOTAL
*       Y(K) = 0.0
```

```
*50   CONTINUE
*     L=1
*     M=4
*     DO 60 K=1,LTOTAL
*     DO 70 J=L,M
*     Y(K) = Y(K) + RDET(J)/4.
*70   CONTINUE
*     L=L+4
*     M=M+4
*60   CONTINUE
*     WRITE(18,5010) (RDET(K),K=1,NTOTAL)
*5010FORMAT(2X,F15.4)
      WRITE(9,*) 'ENTER 1 TO CONTINUE'
      READ(9,*) Q
      IF(Q=1) GO TO 98
      STOP
      END

**********************************************************************
      FUNCTION Rand(IX)
*
* This random number generator is a variation on Tausworthe
* generator described in "Solution of Statistical Distribution
* Problems" by H. O. Hartley in Statistical Methods for Digital
* Computers Vol. III, edited by Enstein, Ralston, and Wilf
* (John Wiley and Sons 1977) . The only modification of consequence
* is the ability to reseed the generator with the system tickcount.
*
* The function returns a real value between 0 and 1.
* Rand(0) will reseed the random sequence using  system tickcount.
* Rand(1) will use previous calls values as seeds for next number
* in the sequence. Always using Rand(1) will generate a specific
* random sequence based upon starting values internal to
* the function.
*
      Real*4 Factor,Ku1,Ku2
      Integer*4 toolbx, BITXOR, TICKCOUNT    ! toolbox definitions
      Integer*4 KU3,LU1,KC,N2TM,N2TCM
      Equivalence (KU2,KU3) , (KU1,LU1)
      PARAMETER (BITXOR=Z'85992000')            ! toolbox definitions
      PARAMETER (TICKCOUNT=Z'97580000')          ! toolbox definitions
* Note that the parameter statement assigns a value to
* the indicated constant label. In this case, it is the indey
```

```
* into a table of trap addresses contained in TOOLBX.SUB which
* converts the call to a trap call. A list of these assignments
* is given in the file TOOLBX.PAR.
*
* You must explicitly tell MacFortran to save the values of
* local variables across sucessive calls of the subroutines.
*
      SAVE
      Data Factor/0.4656613e-9/
      Data N2TCM/z'00040000'/
      Data KU1,KC,N2TM/z'40000003',z'7fffffff',z'00002000'/

* KU1   enters with U(I) uniform random variable
* KU2   leaves with U(I+1) uniform random variable
* KCU1  complement of KU1
* KCU2  complement of KU2
* KC    complementing constant
* LXXX□ logical equivalences of above LXXX
* N2TM  2**M where M is shift factor
* n2TCM 2**P-M where P is word size
* Factor float value of 2**P
* XOR is the exclusive or operator


      if (IX=0) KU1=toolbx(TICKCOUNT)
      KU1=toolbx(BITXOR,KU1,LU1/N2TM)
      KU2=toolbx(BITXOR,KU1,(LU1*N2TCM) .and. KC)
      Rand=FLOAT(KU3)*Factor
      KU1=KU2
      RETURN
      END
*****************************************************
C     A COOLEY-TUKEY RADIX-4 DIF FFT PROGRAM
C     COMPLEX INPUT DATA IN ARRAYS X AND Y
C
C
C
C-------------------------------------------------------------
      SUBROUTINE FFT4 (X,Y,N,M)
      REAL X(1024), Y(1024)
      REAL*8 E
C----------------MAIN FFT LOOPS----------------------------------
      N2 = N
```

```
      DO 10 K = 1,M
        N1 = N2
        N2 = N2/4
        E = 6.283185307179586/N1
        A = 0
        DO 20 J = 1,N2
          B = A + A
          C = A + B
          CO1 = COS(A)
          CO2 = COS(B)
          CO3 = COS(C)
          SI1 = SIN(A)
          SI2 = SIN(B)
          SI3 = SIN(C)
          A   = J*E
          DO 30 I=J, N, N1
            I1 = I + N2
              I2 = I1 + N2
              I3 = I2 + N2
              R1 = X(I) + X(I2)
              R3 = X(I) - X(I2)
              S1 = Y(I) + Y(I2)
              S3 = Y(I) - Y(I2)
              R2 = X(I1) + X(I3)
              R4 = X(I1) - X(I3)
              S2 = Y(I1) + Y(I3)
              S4 = Y(I1) - Y(I3)
              X(I) = R1 + R2
              R2 = R1 - R2
              R1 = R3 - S4
              R3 = R3 + S4
              Y(I) = S1 + S2
              S2 = S1 - S2
              S1 = S3 + R4
              S3 = S3 - R4
              X(I1) = CO1*R3 + SI1*S3
              Y(I1) = CO1*S3 - SI1*R3
              X(I2) = CO2*R2 + SI2*S2
              Y(I2) = CO2*S2 - SI2*R2
              X(I3) = CO3*R1 + SI3*S1
              Y(I3) = CO3*S1 - SI3*R1
30        CONTINUE
20      CONTINUE
```

```
10    CONTINUE
C--------------DIGIT REVERSE COUNTER---------------------------
100   J=1
      N1 = N - 1
      DO 104 I=1, N1
        IF (I.GE.J) GOTO 101
        R1   = X(J)
        X(J) = X(I)
        X(I) = R1
        R1   = Y(J)
        Y(J) = Y(I)
        Y(I) = R1
101   K = N/4
102   IF (K*3.GE.J) GOTO 103
        J = J - K*3
        K = K/4
        GOTO 102
103   J = J + K
104   CONTINUE
      RETURN
      END
```

5.0 RESULTS AND CONCLUSIONS

The previous pages of this report have documented the development of the Sensor model. In this section model validation and verification will be demonstrated. In order to validate the model a received signal disturbed only by Guassian noise was assumed and the signal processing was examined at intermediate points within the model to see if the model was behaving as one would expect.

The assumed signal parameters for the validation runs were F_{IF} = 10 MHz and a pulsewidths of 10,20, and 50 µsec.

A FFT routine was used to observe the output of the IF bandpass filter.The results of two runs of SNRs of 0 db and 10 db (SNR measured at input of IF filter) are depicted in Figure 5.1. As expected the output is a bandpass spectrum centered at 10MHz with a spectral width of 10 MHz. Next the output of the detector lowpass filter was observed. This is illustrated in Figure 5.2. Again we see what one would hope to. A lowpass spectrum of spectral width of about 5 Mhz (adequate to accurately reproduce pulsewidths of 2 µsec and greater) and the signal energy concentrated at the lower frequencies.

Figures 5.3, 5.4, and 5.5 depict time domain plots of the detector output. The received pulse SNR was 20 db, 13 db, and 3 db respectively in the IF bandwidth. The stronger pulses were detected and the pulsewidth of 50 µsec correctly measured. At a SNR = 3db false detection occurred and pulsewidth was incorrectly measured. The plots as shown have been smoothed to facilitate the plotting process. This enhances the SNR as seen in the plots and the detector was working at a SNR of about 13db less than one would estimate by looking at the plots alone.

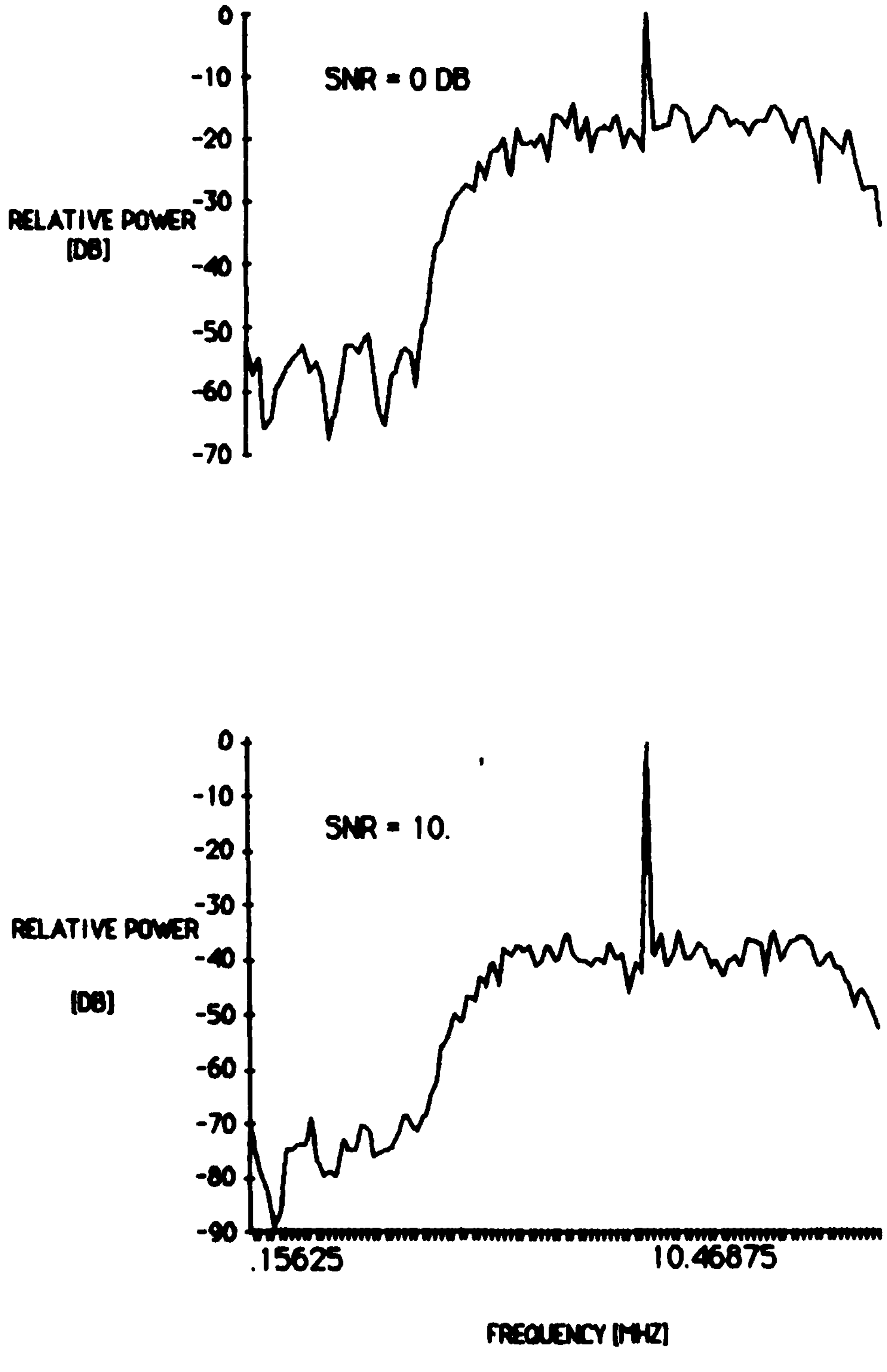

FIGURE 5.1. SPECTRAL PLOTS OF THE SIGNAL AT THE OUTPUT OF THE I.F. FILTER

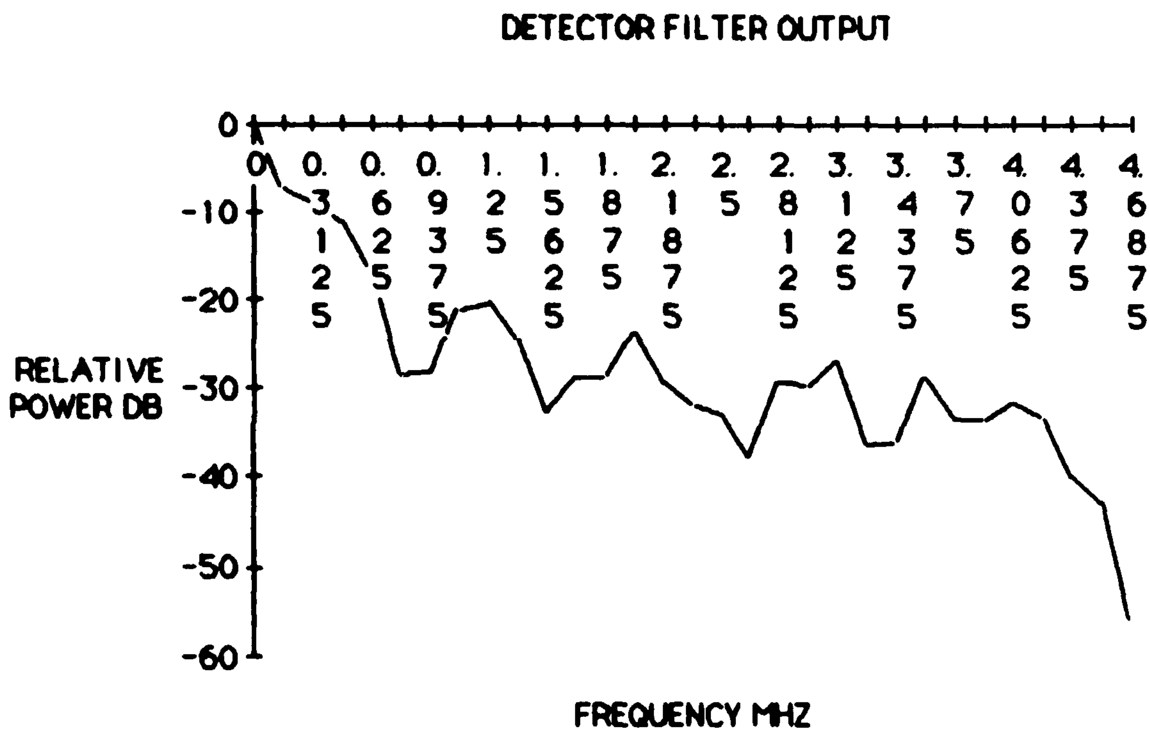

FIGURE 5.2. DETECTOR LOWPASS FILTER SPECTRAL OUTPUT.

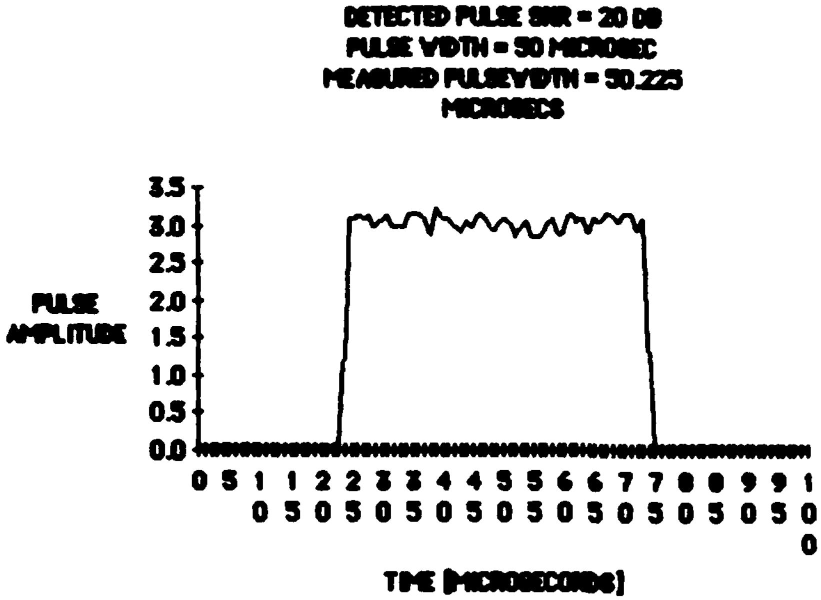

FIGURE 5.3. DETECTED PULSE WITH HIGH SNR

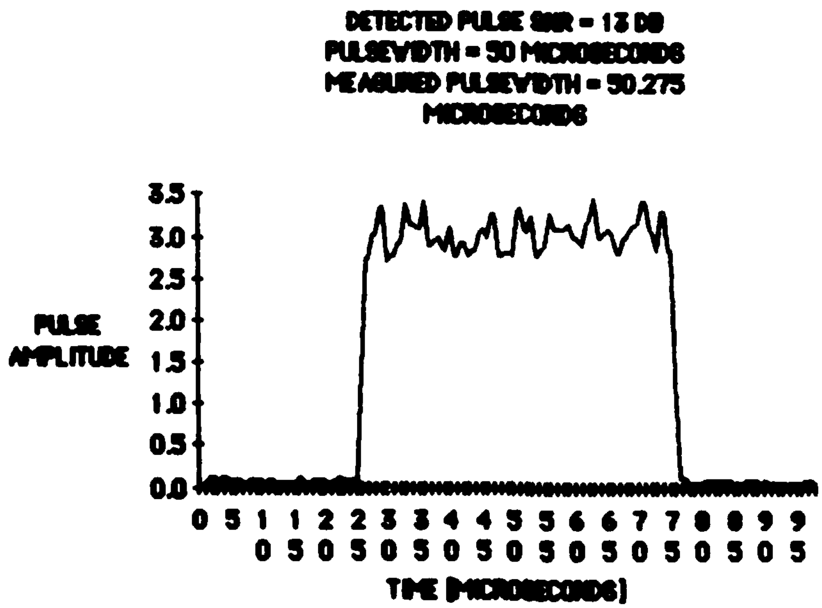

FIGURE 5.4. DETECTED PULSE OF LOWER SNR.

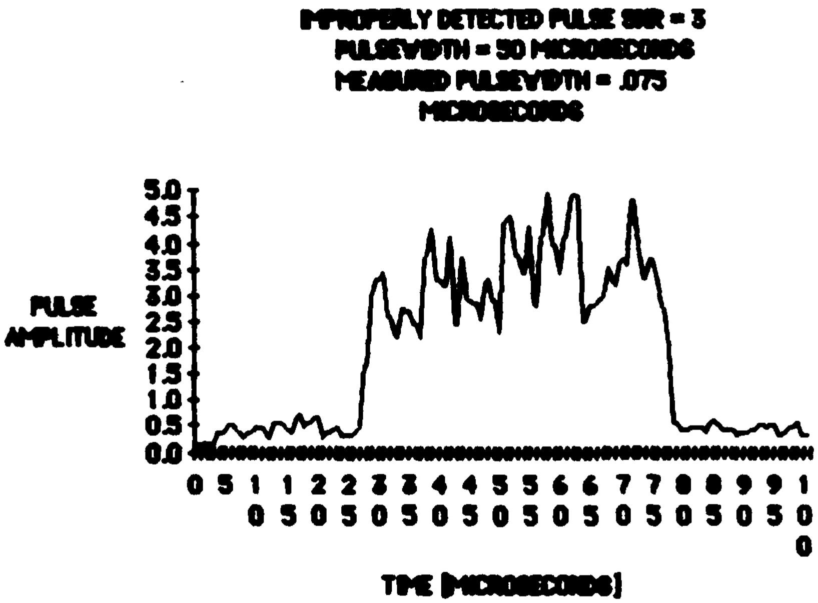

FIGURE 5.5. PULSE OF LOW SNR THAT WAS NOT PROPERLY DETECTED

The model was exercised many times with received signals of varying SNRs and then the measured probabilty of detection was compared to theoretical as documented in many standard references*. A plot of SNR vs. Probability of Detection for this model is presented in Figure Eight.

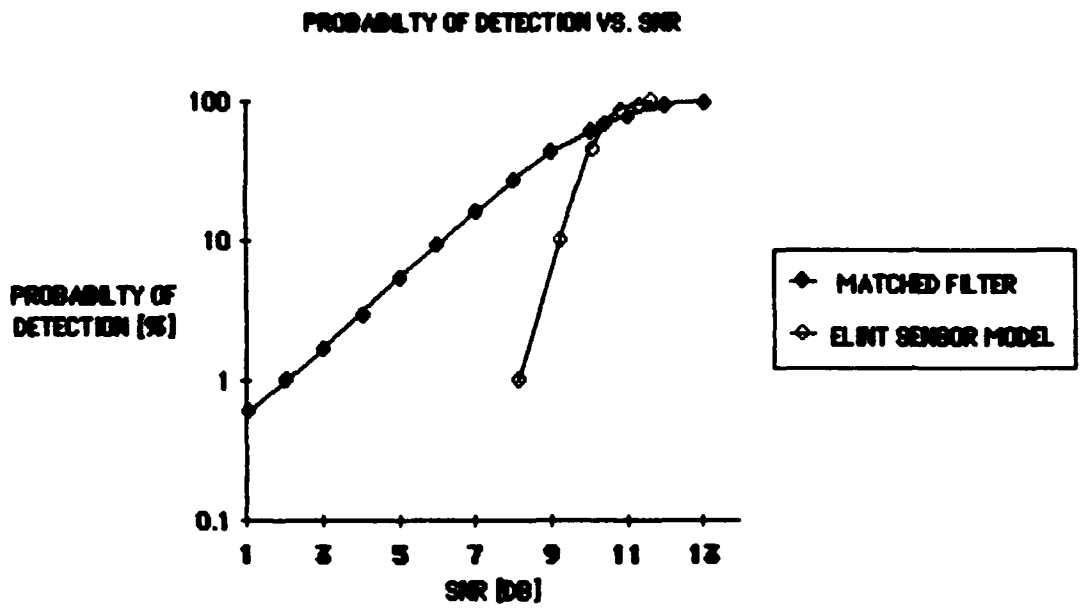

FIGURE 5.6. PROBABILTY OF DETECTION VS. SNR PLOT FOR THE ELINT SENSOR MODEL

As can be seen performance is comparable at high SNRs but degrades rapidly as SNR decreases. This is because the detection process modeled is not matched filter detection and is not optimum at lower SNRs but is instead designed to reproduce a detected pulse with sufficient fidelity to provide good pulse parameter measurement capabilty.

In conclusion, then, it can be said that the sensor model at its present state of development performs as expected when excited with signals plus Gaussian noise and will provide a tool by which the output distributions of other types of signals may be studied.

* *SEE FOR INSTANCE "RADAR TARGET DETECTION HAND BOOK OF THEORY AND PRACTICE " BY MEYER AND MAYER*

END

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